Wilson Bull., 102(2), 1990, pp. 264–278

EFFECTS OF FOREST IRRIGATION ON LONG-TERM TRENDS IN BREEDING-BIRD COMMUNITIES

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Abstract.—We conducted a long-term study of breeding-bird communities in a deciduous forest irrigated with chlorinated effluent (wastewater) and in a non-irrigated forest in central Pennsylvania. Birds were mist-netted in both forests (sites) each summer during a pre-irrigation era (1978–82) and an irrigation era (1983–87). Community structure and return rates of common species were compared between sites and between eras. Seventy-five species were netted during the ten years. During the pre-irrigation era, no species was significantly more abundant on the irrigated than the non-irrigated site, whereas five species were more abundant on the non-irrigated site. During the irrigation era, five species were more common on the irrigated sites, and four were more common on the non-irrigated site. Four species had lower return rates on the irrigated compared to the non-irrigated site, and two had higher rates on the irrigated site. Based on pairwise comparisons of percent similarity, changes in breeding-bird communities from pre-irrigation to irrigation eras were more dramatic on the irrigated than the non-irrigated site. In particular, bird species diversity and evenness declined on the irrigated site. Most avian responses to wastewater irrigation could be explained by irrigation-induced changes in vegetation. Common Yellowthroats (*Geothlypis trichas*), Indigo Buntings (*Passerina cyanea*), and Song Sparrows (*Melospiza melodia*) were benefited by forest irrigation, but Wood Thrushes (*Hylocichla mustelina*) were negatively affected by irrigation. *Received 13 March 1989, accepted 24 Aug. 1989.*

Human-induced changes in forest habitat can have dramatic effects on food supply, nest sites, singing perches, and cover for birds, consequently altering avian community structure (Johnston 1970, Noon et al. 1979, Maurer et al. 1981, Yahner 1986). The extent of change in avian community structure in an altered environment depends on habitat requirements of individual species in the community (Best et al. 1978).

Irrigation of forests with chlorinated effluent (wastewater) affects plant community structure and composition (Rollfinke 1988), yet little is known regarding the effects of forest irrigation on wildlife. Three previous studies of forest bird communities associated with wastewater irrigation were largely inconclusive because of the small size of experimental plots, short duration of study periods, and irregular or partial-year irrigation schedules (Savidge and Davis 1971, Snider 1974, Lewis and Samson 1981). Thus, relationships between irrigation-induced habitat changes and avian community structure have been inferred but not clearly documented

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(Greenwald 1981). Our objective was to compare long-term trends in breeding-bird communities prior to irrigation with wastewater (1978–82) and during irrigation (1983–87) on an irrigated and a non-irrigated forest in central Pennsylvania.

STUDY AREA AND METHODS

We conducted the study in a forest irrigated with wastewater and in a non-irrigated forest in Centre County, Pennsylvania, from 1978–87 (see details in Rollfinke 1988). The irrigated forest contained a 200-ha wastewater spray-irrigation system, which started year-round operation in April 1983. The system consisted of about 3100 rotating sprinklers connected by a network of pipes that applied about 264 cm of wastewater annually. Average annual precipitation in central Pennsylvania is 93 cm (Matula 1983). The non-irrigated forest was 3 km northwest of the irrigated forest and was part of a contiguous forest tract at the base of Bald Eagle Mountain.

One mist-net site each was established on the irrigated and non-irrigated forests in 1978 (hereafter referred to as irrigated and non-irrigated sites, respectively). Sixteen nets (3.8-cm mesh, 2.1 m × 5.5 m), arranged in a 4 × 4 grid pattern and spaced 30 to 60 m apart, were used at each site to include an area of about 3 ha per site. Both sites included old fields (33%) and deciduous forest (67%) and contained overstory trees from 30 to 60 years old.

Overstory trees (≥7.5 cm dbh) on the irrigated site were primarily quaking aspen (*Populus tremuloides*), bigtooth aspen (*P. grandidentata*), scarlet oak (*Quercus coccinea*), black oak (*Q. velutina*), northern red oak (*Q. rubra*), and red maple (*Acer rubrum*). Predominant understory trees (2.5–7.5 cm dbh) and shrubs (<2.5 cm in diameter) included quaking aspen, red maple, rose (*Rosa* spp.), and Tartarian honeysuckle (*Lonicera tatarica*). Major overstory trees on the non-irrigated site included bigtooth aspen, slippery elm (*Ulmus rubra*), hawthorn (*Crataegus* spp.), and white ash (*Fraxinus americana*). Common understory trees and shrubs on the non-irrigated sites were hawthorn, flowering dogwood (*Cornus florida*), common spicebush (*Lindera benzoin*), and Tartarian honeysuckle.

The elevation of the irrigated site was 370–385 m; the non-irrigated site was 365–395 m in elevation. Four ponds formed during the study on the irrigated site; these were about 0.14, 0.13, 0.06, and 0.03 ha in size by summer 1987. There was no standing water on the non-irrigated site, except for a small temporary stream that dried early each summer.

We sampled vegetation at eight random 0.04-ha circular plots per site in summer 1987. Unfortunately, no vegetation data were collected on the two sites prior to irrigation; however, other investigators have documented changes in forest vegetation resulting from operation of this irrigation system (Rollfinke 1988) or its prototypes (Sopper and Kardos 1973, Lewis 1977) within 1 km of our irrigated site. Densities (no./ha) of overstory live trees and snags, stumps (<1.5 m tall, >7.5 cm diameter), logs (≥1 m length, >7.5 cm diameter), and lianas (woody vines ≥1.5 m high, ≥1.0 cm diameter) were determined within each 0.04-ha plot. Densities (no./ha) of understory trees, tall shrubs (≥1.5 m tall), and short shrubs (0.5–1.5 m tall) were quantified in two perpendicular 1-m wide transects within each plot. Percent (%) coverages of herbs, woody vegetation, leaf litter, bare ground, rock, clubmoss, ferns, and logs at ground level and of canopy were determined by taking 20 ocular tube sightings spaced at 2-m intervals along the perpendicular transects. Densities (no./m^2) of tall herbs and ferns (≥0.5 m in height) were determined in four random 1 m^2 subplots within each 0.04-ha plot. Habitat variables were compared between irrigated and non-irrigated sites using Mann-Whitney tests (Sokal and Rohlf 1981). A significance level of $P < 0.05$ was used in all statistical tests.

We mist-netted birds over ten consecutive summers (1978–87) at each site, producing five years of data both before and during irrigation. Mist-netting was conducted once per week for 13 weeks each summer (early June-late August). The orientation of each mist net was changed from weeks 6 to 9 (generally a 90° pivot around one net pole) to minimize net shyness and to increase capture success (Keyes and Grue 1982).

We opened nets from 0530 to 1100 hours; nets were closed earlier if exposed to direct sunlight on hot days in order to prevent netted birds from overheating (Keyes and Grue 1982). Birds were not netted on mornings with heavy rain or while wastewater was being sprayed (12-h period every 2 weeks). Nets generally were open for 70 h per site each summer. Total net-h were about 1120 per site per year, resulting in over 22,000 net-h during the study.

Each captured bird was identified, aged, sexed (if possible), and banded with a U.S. Fish and Wildlife Service leg band. Birds also were weighed, checked for molt, and measured (mm) for wing, tail, and tarsus length before release. Previously banded birds were classified as "recaptures" if they had been netted earlier that same summer and "returns" if they had been netted in a previous summer. Adult birds (after hatching year), which were netted within the breeding "safe dates" (Gill et al. 1984), were considered resident breeding birds.

Numbers of individuals (C) of each species netted per year (including returning birds banded in earlier years), total number of individual birds of all species combined (N), species richness (S), species diversity (H'), and species evenness (J') were used as measures of community structure and were calculated per year at each site. S = the total number of species; $H' = -\Sigma p_i \log_e p_i$, where p_i is the proportion of individuals of the ith species; and $J' = H'/\log_e S$. C for 18 common species (those with $\geq$20 resident breeding individuals for all years and both sites combined), N, S, H', and J' were compared between sites and between the two 5-year eras (pre-irrigation and irrigation) using Mann-Whitney tests. Pairwise comparisons of percent similarity (PS) in these resident breeding communities were calculated between eras within a given site and between sites within a given era, where $PS = \Sigma(x_i$ or y_i, whichever is lower), where x_i and y_i are the percent composition of species i in the first and second communities, respectively (Brower and Zar 1984).

Percentages of banded birds that returned in subsequent years were determined at each site for each of the 18 most common breeding species and for all species combined. Return rates were compared between sites using arcsine tests for equality of two percentages (Sokal and Rohlf 1969).

RESULTS

Vegetation differences between sites.—Thirteen and 15 overstory tree species were found on the irrigated and non-irrigated sites, respectively. Overstory trees on the irrigated site had greater dbh ($P < 0.01$) than those on the non-irrigated site (Table 1). Densities of both understory trees and tall shrubs were lower ($P < 0.05$) on the irrigated site than on the non-irrigated site, presumably because of mortality and breakage of trees and shrubs from heavy ice accumulation during winter irrigation (Sopper and Kardos 1973, Rollfinke 1988). Density of herbaceous cover was higher on the irrigated site, but differences between sites were not significant ($P > 0.05$), perhaps because of high within-site variability and small number ($N = 8$) of sampling plots per site (Rollfinke 1988).

Avian differences between sites and eras.—Sixty-nine bird species were netted on the irrigated site and 63 on the non-irrigated site during the ten

TABLE 1

MEANS (± SD) OF SELECTED HABITAT VARIABLES, BASED ON EIGHT 0.04-HA CIRCULAR PLOTS EACH ON AN IRRIGATED AND A NON-IRRIGATED FORESTED SITE, CENTRE COUNTY, PENNSYLVANIA, 1987

Variable	Site	
	Irrigated	Non-irrigated
Overstory tree (all species combined):		
Density (no./ha)	512.5 ± 326.8	409.3 ± 230.0
dbh (cm)	16.4 ± 5.8**	13.6 ± 7.8
Basal area (m^2/ha)	12.1 ± 8.5	7.9 ± 5.9
Understory tree (all species combined):		
Density (no./ha)	603.1 ± 583.3*	1480.3 ± 818.0
Tall shrub (all species combined):		
Density (no./ha)	2467.1 ± 1605.3*	6688.6 ± 3103.1
Short shrub (all species combined):		
Density (no./ha)	13,486.8 ± 7151.3	13,953.9 ± 6223.7
Tall herb/fern (all species combined):		
Density (no./ha)	42,825.0 ± 72,800.0	18,450.0 ± 26,125.0
Physical features: density (no./ha)		
Logs	150.0 ± 157.5	75.0 ± 125.3
Stumps	9.4 ± 12.9	31.3 ± 70.4
Lianas	140.8 ± 151.8	284.5 ± 186.5
Percent (%) coverage:		
Canopy	69.4 ± 28.2	81.3 ± 15.3
Herbaceous ground cover	35.6 ± 19.7	21.3 ± 15.3
Woody ground cover	11.9 ± 16.7	18.1 ± 21.2
Leaf litter	46.9 ± 26.9	39.4 ± 22.6

* $P < 0.05$, ** $P < 0.01$. Significant difference between sites, Mann-Whitney test.

years. Of the 75 species netted on both sites, 56 were species known to breed in the vicinity of our mist-net sites (Wood 1983).

The five most common species on the irrigated site were, in decreasing order of abundance, Song Sparrow (scientific names in Table 2), Gray Catbird, Indigo Bunting, Common Yellowthroat, and Rufous-sided Towhee (Table 2). The most common species on the non-irrigated site were Gray Catbird, Wood Thrush, Red-eyed Vireo, Ovenbird, and Song Sparrow.

During the pre-irrigation era, none of the 18 common species was more abundant on the irrigated as compared to the non-irrigated site, whereas five common species were captured significantly more often on the non-

TABLE 2

TOTAL NUMBER OF INDIVIDUALS NETTED OF 18 COMMON BREEDING SPECIES AND OF ALL SPECIES COMBINED, SPECIES RICHNESS, DIVERSITY, AND EVENNESS OF BIRDS MIST-NETTED (INCLUDING BIRDS BANDED FOR THE FIRST TIME AND RETURNING BIRDS BANDED IN EARLIER YEARS) PER YEAR AT AN IRRIGATED AND A NON-IRRIGATED SITE, CENTRE COUNTY, PENNSYLVANIA, 1978–87

	Era and year											
	Pre-irrigation						Irrigation					
Species	78	79	80	81	82	Mean ± SD	83	84	85	86	87	Mean ± SD
Downy Woodpecker (*Picoides pubescens*)												
Irrigated	6	1	11	9	7	6.8 ± 3.8	4	3	4	10	9	6.0 ± 3.2[b]
Non-irrigated	3	1	1	6	0	2.2 ± 2.4	2	0	1	3	2	1.6 ± 1.1[b]
Black-capped Chickadee (*Parus atricapillus*)												
Irrigated	5	10	6	9	3	6.6 ± 2.9	5	5	7	7	9	6.6 ± 1.7
Non-irrigated	2	7	10	11	9	7.8 ± 3.6	5	6	12	2	6	6.2 ± 3.6
Wood Thrush (*Hylocichla mustelina*)												
Irrigated	12	7	9	6	9	8.6 ± 2.3[a,c]	3	2	2	4	0	2.2 ± 1.5[b,c]
Non-irrigated	19	32	35	18	29	26.6 ± 7.7[a,d]	53	39	38	41	60	46.2 ± 9.8[b,d]
American Robin (*Turdus migratorius*)												
Irrigated	4	1	0	2	4	2.2 ± 1.8	2	5	4	9	4	4.8 ± 2.6[b]
Non-irrigated	0	2	0	1	0	0.6 ± 0.9	0	1	0	0	2	0.6 ± 0.9[b]
Gray Catbird (*Dumetella carolinensis*)												
Irrigated	36	34	40	42	39	38.2 ± 3.2	48	51	38	30	60	45.4 ± 11.7
Non-irrigated	42	52	45	40	35	42.8 ± 6.3	31	43	33	28	31	33.2 ± 5.8
Red-Eyed Vireo (*Vireo olivaceus*)												
Irrigated	0	2	2	3	3	2.0 ± 1.2[a]	4	2	1	1	2	2.0 ± 1.2[b]
Non-irrigated	4	17	5	17	12	11.0 ± 6.3[a]	4	8	10	9	10	8.2 ± 2.5[b]

TABLE 2
CONTINUED

Species	Era and year											
	Pre-irrigation						Irrigation					
	78	79	80	81	82	Mean ± SD	83	84	85	86	87	Mean ± SD
Golden-winged Warbler (*Vermivora chrysoptera*)												
Irrigated	1	0	0	3	0	0.8 ± 1.3[a]	0	3	1	0	1	1.0 ± 1.2[b]
Non-irrigated	5	8	4	2	3	4.4 ± 2.3[a]	6	5	2	3	5	4.2 ± 1.6[b]
Worm-eating Warbler (*Helmitheros vermivorus*)												
Irrigated	0	1	3	8	0	2.4 ± 3.4	1	3	1	1	4	2.0 ± 1.4
Non-irrigated	5	3	9	8	0	5.0 ± 3.7	4	6	4	1	5	4.0 ± 1.9
Ovenbird (*Seiurus aurocapillus*)												
Irrigated	6	9	9	4	10	7.6 ± 2.5	9	10	8	6	7	8.0 ± 1.6
Non-irrigated	4	2	6	3	6	4.2 ± 1.8	7	5	15	20	14	12.2 ± 6.1
Common Yellowthroat (*Geothlypis trichas*)												
Irrigated	3	0	6	8	5	4.4 ± 3.1[c]	14	14	12	19	23	16.4 ± 4.5[b,c]
Non-irrigated	4	2	5	1	4	3.2 ± 1.6[d]	8	7	6	10	5	7.2 ± 1.9[b,d]
Yellow-breasted Chat (*Icteria virens*)												
Irrigated	2	4	7	8	0	4.2 ± 3.4	1	6	2	0	0	1.8 ± 2.5
Non-irrigated	5	0	3	0	0	1.6 ± 2.3	0	0	0	0	0	0.0 ± 0.0
Scarlet Tanager (*Piranga olivacea*)												
Irrigated	2	1	0	0	2	1.0 ± 1.0	0	0	1	0	2	0.6 ± 0.9
Non-irrigated	1	6	1	2	8	3.6 ± 3.2	1	3	3	1	4	2.4 ± 1.3
Northern Cardinal (*Cardinalis cardinalis*)												
Irrigated	2	2	8	10	6	5.6 ± 3.6	3	2	4	3	13	5.0 ± 4.5
Non-irrigated	9	4	2	7	10	6.4 ± 3.4	4	6	3	9	13	7.0 ± 4.1

TABLE 2
CONTINUED

Species	Era and year											
	Pre-irrigation						Irrigation					
	78	79	80	81	82	Mean ± SD	83	84	85	86	87	Mean ± SD
Indigo Bunting (*Passerina cyanea*)												
Irrigated	3	8	7	11	8	7.4 ± 2.9^{c}	16	23	19	29	34	$24.2 \pm 7.3^{b,c}$
Non-irrigated	0	0	9	5	9	4.6 ± 4.5	4	3	2	3	4	3.2 ± 0.8^{b}
Rufous-sided Towhee (*Pipilo erythrophthalmus*)												
Irrigated	9	9	12	6	10	9.2 ± 2.2	5	7	6	7	11	7.2 ± 2.3
Non-irrigated	7	11	5	5	13	8.2 ± 3.6	6	5	5	10	6	6.4 ± 2.1
Field Sparrow (*Spizella pusilla*)												
Irrigated	7	8	6	6	3	$6.0 \pm 1.9^{a,c}$	2	0	0	0	1	$0.6 \pm 0.9^{b,c}$
Non-irrigated	10	12	15	7	10	$10.8 \pm 3.0^{a,d}$	10	6	5	3	4	$5.6 \pm 2.7^{b,d}$
Song Sparrow (*Melospiza melodia*)												
Irrigated	10	5	15	45	27	20.4 ± 16.0^{c}	32	52	28	69	116	$59.4 \pm 35.7^{b,c}$
Non-irrigated	7	9	11	5	7	7.8 ± 2.3	8	7	5	8	9	7.4 ± 1.5^{b}
American Goldfinch (*Carduelis tristis*)												
Irrigated	0	1	2	2	0	1.0 ± 1.0^{a}	4	5	3	0	21	6.6 ± 8.3
Non-irrigated	7	1	6	4	7	5.0 ± 2.6^{a}	0	4	10	0	1	3.0 ± 4.2
Total number of birds (*N*)												
Irrigated	128	124	187	224	174	167 ± 42	180	221	174	229	384	248 ± 85
Non-irrigated	162	221	212	187	200	196 ± 23	184	200	181	193	201	192 ± 9

TABLE 2
CONTINUED

Species	Era and year											
	Pre-irrigation						Irrigation					
	78	79	80	81	82	Mean ± SD	83	84	85	86	87	Mean ± SD
Total number of species (S)												
Irrigated	24	32	30	35	31	30.4 ± 4.0	35	34	33	30	36	33.6 ± 2.3
Non-irrigated	31	41	32	36	34	34.8 ± 4.0	29	33	28	37	28	31.0 ± 4.0
Species diversity (H')												
Irrigated	2.65	2.78	2.96	2.88	2.86	2.83 ± 0.12[c]	2.68	2.60	2.78	2.51	2.60	2.63 ± 0.10[c]
Non-irrigated	2.84	2.94	2.88	3.02	2.96	2.93 ± 0.07	2.66	2.88	2.71	2.90	2.59	2.75 ± 0.14
Species evenness (J')												
Irrigated	0.83	0.80	0.87	0.81	0.83	0.83 ± 0.03[c]	0.75	0.74	0.80	0.74	0.73	0.75 ± 0.03[b,c]
Non-irrigated	0.83	0.79	0.83	0.84	0.84	0.83 ± 0.02	0.79	0.83	0.81	0.80	0.78	0.80 ± 0.02[b]

[a] Significant difference between sites during pre-irrigation era (1978–82), $P < 0.05$, Mann-Whitney test.
[b] Significant difference between sites during irrigation era (1983–87), $P < 0.05$, Mann-Whitney test.
[c] Significant difference between 5-year eras at irrigated site, $P < 0.05$, Mann-Whitney test.
[d] Significant difference between 5-year eras at non-irrigated site, $P < 0.05$, Mann-Whitney test.

irrigated site (Table 2). During the irrigation era, four of the five species (Wood Thrush, Red-eyed Vireo, Golden-winged Warbler, and Field Sparrow) also were more abundant on the non-irrigated site than the irrigated site, but Downy Woodpecker, American Robin, Common Yellowthroat, Indigo Bunting, and Song Sparrow were considerably more abundant on the irrigated site. As a result of three-fold increases in the latter three species, H' and J' declined on the irrigated site during the irrigation era.

Based on *PS,* the breeding-bird community changed more between eras on the irrigated (71% similarity between eras) than on the non-irrigated site (81%). The communities were relatively more similar on the two sites during the pre-irrigation era (66%) than during the irrigation era (53%).

Over 6% of the total birds banded on each site were recaptured in subsequent years (Table 3). Wood Thrush, Red-eyed Vireo, Golden-winged Warbler, and Rufous-sided Towhee had lower return frequencies on the irrigated than the non-irrigated site. Song Sparrow and Gray Catbird had higher return rates on the irrigated site. Northern Cardinal and Field Sparrow had the highest return rates (18% and 17%, respectively, for both mist-net sites combined) of the species studied.

DISCUSSION

Responses of vegetation to installation and implementation of the irrigation system.—Habitat alteration on the irrigated site occurred in two phases. In the first phase, parallel lanes were cleared through the forest for installation of sprinkler lines. These lanes were about 1.2 m (1987) to 4.0 m wide (1978) and were spaced 27 m apart. Thus, tree density was reduced slightly, and narrow gaps in the canopy were created. We feel that habitat alterations resulting from this phase were relatively insignificant compared to that of the second phase.

In the second phase, year-round irrigation of wastewater caused dramatic changes in vegetation. Larger mean dbh of overstory trees on the irrigated than the non-irrigated site was attributed to increased growth rates resulting from added water and nutrients rather than to differences in ages of forest stands between sites (Sopper and Kardos 1973). Ice buildup in winter and a concomitant reduction in densities of understory and shrubby vegetation on the irrigated site presumably decreased the availability of food and cover resources for birds (Lewis and Samson 1981, Rollfinke 1988).

Although density of herbaceous vegetation was not significantly different between sites in our study, others have shown that irrigated forests have taller and lusher herbaceous vegetation than non-irrigated forests (Sopper and Kardos 1973, Mastrota et al. 1990). Further, food resources, such as berries, seeds, and invertebrates, were considerably more abun-

TABLE 3
TOTAL NUMBER OF BIRDS BANDED AND NUMBER AND RATES OF BIRDS RETURNING IN SUBSEQUENT YEARS FOR 18 COMMON BREEDING SPECIES AND FOR ALL SPECIES COMBINED ON AN IRRIGATED (I) AND A NON-IRRIGATED (N) FORESTED SITE, CENTRE COUNTY, PENNSYLVANIA, 1978–87

Species	Site	No. banded	No. returns	Return rate (%)
Downy Woodpecker	I	57	6	10.5
	N	18	1	5.6
Black-capped Chickadee	I	62	3	4.8
	N	62	7	11.3
Wood Thrush[a]	I	54	0	0.0
	N	336	20	6.0
American Robin	I	35	0	0.0
	N	6	0	0.0
Gray Catbird[a]	I	351	41	11.7
	N	346	24	6.9
Red-eyed Vireo[a]	I	20	0	0.0
	N	88	9	10.2
Golden-winged Warbler[a]	I	9	0	0.0
	N	37	5	13.5
Worm-eating Warbler	I	22	0	0.0
	N	45	0	0.0
Ovenbird	I	71	6	8.5
	N	80	2	2.5
Common Yellowthroat	I	92	10	10.9
	N	48	2	4.2
Yellow-breasted Chat	I	30	0	0.0
	N	8	0	0.0
Scarlet Tanager	I	8	0	0.0
	N	30	0	0.0
Northern Cardinal	I	39	9	23.1
	N	56	8	14.3
Indigo Bunting	I	142	10	7.0
	N	37	2	5.4
Rufous-sided Towhee[a]	I	77	2	2.6
	N	57	10	17.5
Field Sparrow	I	29	4	13.8
	N	66	12	18.2
Song Sparrow[a]	I	367	22	6.0
	N	75	1	1.3
American Goldfinch	I	37	1	2.7
	N	40	0	0.0
Total (all species)	I	1852	118	6.4
	N	1797	110	6.1

[a] Significant difference in return rates between sites, $P < 0.05$, arcsine test for equality of two percentages.

dant in irrigated than non-irrigated forests (Lewis 1977, Greenwald 1981, Mastrota et al. 1990).

Avian community response to irrigation.—Avian community structure is associated with vertical and horizontal complexity of forest vegetation (MacArthur and MacArthur 1961, Roth 1976) and local moisture conditions that may affect food supplies (Smith 1977, Swift et al. 1984, Petit et al. 1985). Because the first phase of habitat alteration created by installation of the irrigation system had limited effects on vegetative complexity, we feel that this phase had minimal effects on avian community structure on the irrigated site. Moreover, if clearing of vegetation for pipelines was the primary cause of changes in abundance of the avifauna, these changes would be expected immediately in 1983, which was the year of system installation. Instead, we observed a steady but gradual change in avifauna subsequent to system installation, corresponding with changes in vegetation structure. Thus, we contend that changes in avifauna between the two sites were attributed principally to the second phase of habitat alteration, i.e., irrigation, which increased habitat heterogeneity and reduced habitat for forest specialists.

In general, we found avian responses to forest irrigation with wastewater to be more dramatic than suggested in earlier studies. Savidge and Davis (1971) found no significant changes in an avian community associated with a young woodlot with over five years of irrigation, except for an increase in American Robins. Both Snider (1974) and Lewis and Samson (1981) reported significantly lower breeding-bird densities on irrigated mature oak sites than on undisturbed mature sites; however, they found increased avian densities in irrigated young aspen-pine (*Pinus*) stands. We found a dramatic increase in total bird numbers on the irrigated site after the onset of irrigation, primarily because several forest-edge species became much more abundant relative to other species. In addition, species composition on the irrigated site during the irrigation era was very dissimilar (*PS*) compared to that on the irrigated site prior to irrigation or to community structure on the non-irrigated site in either era.

Avian species richness (*S*) often declines in stressed or disturbed ecosystems (Adams and Barrett 1976). Evenness (J'), on the other hand, is relatively stable and usually does not fluctuate markedly in response to habitat changes (Kricher 1972, Adams and Barrett 1976). Especially in summer, species diversity (H') varies primarily as a function of species richness and is influenced minimally by species evenness (Rotenberry et al. 1979). In our study, however, species diversity declined with the onset of irrigation on the irrigated site not because of a decrease in richness but because the avian community became dominated by a few forest edge species, causing a significant decline in J'.

Individual species responses to irrigation.—Wastewater irrigation of the forest increased the abundance of edge species, particularly Common Yellowthroats, Indigo Buntings, and Song Sparrows. Yellowthroats and buntings have shown recent population increases in much of the eastern U.S. (Anderson et al. 1981, Robbins et al. 1986), where extensive habitat fragmentation has created increasing amounts of edge (Yahner 1988).

Yellowthroats nest and forage in areas of dense low vegetation, which is typical of moist habitats (Stewart 1953, Yahner 1987). Sedgwick and Knopf (1987) suggested that yellowthroat populations can serve as ecological indicators of the quality of ground/shrub vegetation. Indigo Buntings and Song Sparrows similarly are ground/shrub-foragers associated with dense brushy vegetation and usually are absent from closed-canopy forests (DeGraaf et al. 1980, Maurer et al. 1981, Kahl et al. 1985). Lush growth of herbaceous vegetation and formation of ponds associated with the installation and operation of the irrigation system provided suitable habitat for these species on the irrigated site.

We found that wastewater irrigation may be detrimental to populations of Wood Thrush. Lewis and Samson (1981), however, noted that thrushes increased in a young irrigated forest but decreased on an irrigated mature site. Wood Thrushes prefer forests with moderately dense understory/subcanopy layers because they nest in saplings and shrubs (DeGraaf et al. 1980, Kahl et al. 1985). Thus, winter ice damage to understory trees and shrubs may reduce the availability of nesting sites for thrushes in irrigated forests. Further, because Wood Thrushes methodically forage at ground level (Holmes and Robinson 1988), dense herbaceous growth in irrigated forests may reduce foraging efficiency of this species.

Return rates.—Return rates reflect survival and site fidelity of breeding birds. Van Horne (1983) has recommended that habitat quality for a species be defined in terms of survival as well as abundance. Lower rates of return of banded birds on the irrigated site compared with the non-irrigated site suggest that habitat quality for Wood Thrushes, Red-eyed Vireos, Golden-winged Warblers, and Rufous-sided Towhees was lower on the irrigated site. Red-eyed Vireos and Golden-winged Warblers were not abundant on the site even before irrigation began; thus, the site initially may have been marginal for those species. Lower return rates for Wood Thrushes in the irrigated forest lend support to our previous conclusion that habitat quality declined for this species with the installation and operation of the wastewater system. The lush herbaceous growth in the irrigated forest also may have impacted Rufous-sided Towhees which nest and forage on or near the ground (e.g., Yahner 1987), although their abundance did not change. Higher return rates on the irrigated site for Gray Catbirds and Song Sparrows likely indicate that habitat changes benefited these species, but only Song Sparrows increased significantly in abundance.

Although overall return rates (6.3% for both sites combined) did not differ between irrigated and non-irrigated mist-net sites, these values compared favorably with other studies. Blake (1953) reported a 6.7% return rate for breeding songbirds in Massachusetts. Baumgartner (1986) reported a slightly higher return rate of 8.7%, but her totals included wintering birds attracted to feeders and caught in traps rather than mist-nets. In a two-year study of wastewater-irrigated habitats, Snider (1974) had a 4.9% return rate between years.

ACKNOWLEDGMENTS

We thank E. Bellis and J. Kurland for reviewing an earlier draft of the manuscript. Numerous students assisted in the field; we especially thank B. Andres, R. Bond, G. Hennemuth, C. Kilburn, G. Kojadinovich, L. Morris, S. Pruitt, T. Scott, W. Thompson, and R. Voytko. This study was supported by the Pennsylvania Agricultural Experiment Station and the Max McGraw Wildlife Foundation. This is Journal Series Paper No. 8195 of the Penna. Agric. Exp. Stat., University Park, Pennsylvania.

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